Food Waste: A Healthy and Energizing Alternative to Anaerobic Digestion

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Overview

Why Food Waste?
Food waste is the single largest category of municipal solid waste (MSW) in California at 5.9 million tons or 16% of total MSW as of 1999 (CIWMB, 1999). Food waste comes from a variety of sources including; residential, commercial, industrial, schools, restaurants, etc.

Diverting a portion of food waste from landfills can provide a significant contribution toward achieving EPA, state, and local mandated solid waste diversion goals. The EPA Resource Conservation Challenge (RCC) is a national effort to conserve natural resources and energy by managing materials more efficiently. Since food waste is one of the largest waste streams still being sent to landfills, it is a priority area for increased diversion.

In addition, diverting food waste from landfills prevents uncontrolled emissions of its breakdown products, including methane—a potent greenhouse gas.

Why Anaerobic Digestion?
Currently, only about 2.5% of food waste is recycled nationwide with the principal technology being composting. Composting is an important process that produces a very valuable soil amendment– compost. However, with the increased focus on alternative energy, anaerobic digestion is an ideal preliminary step to composting.

Anaerobic digestion is a process that, in the absence of oxygen, converts organic carbon into carbon dioxide (CO_2) and methane (CH_4)- biogas, which can be used as an energy source. In addition, anaerobic digestion breaks down solids which reduces the end residual product. After recovering the energy value of food waste and reducing the volume, the residual can be transported to a compost facility, processed and returned to soil. This creates a cradle to cradle, sustainable process.

Anaerobic digestion :
- Reduces volatile organic compounds (VOC's) if used prior to composting
- Produces biogas that can be used for energy
- Reduces solids prior to transporting to a compost facility

Why Wastewater Treatment Facilities?
Wastewater treatment facilities have successfully used anaerobic digestion for many years to treat solids in municipal wastewater and produce beneficial end products: methane gas and fertilizer. In California, approximately 137 wastewater treatment plants have anaerobic digesters for treating sludge, with an estimated excess capacity of 15-30%. This excess capacity could provide a potent recycling opportunity for post-consumer food waste.

Wastewater treatment facilities are ideal to anaerobically digest food waste because:
- The facilities are already permitted as solid waste facilities
- Most digesters currently have excess capacity that is not being utilized
- Facilities are located in urban areas, providing a solution for recycling food waste when compost facilities are not feasible
- Biogas produced can be used on site
- Digestion expertise is already available onsite
- Effluent produced can be recycled through treatment facility

At the East Bay Municipal Utility District's (EBMUD) Main Wastewater Treatment Plant (MWWTP), food waste is currently co-digested with primary and secondary municipal wastewater solids and other high-strength wastes. Due to the limitations at full-scale, and risks of overloading digesters, it has been difficult to accurately quantify methane gas production rates, mean cell residence time (MCRT) requirements, and volatile solids reduction values that are specific to food waste digestion. Bench-scale anaerobic digesters were fed only food waste pulp from EBMUD's food waste processing system. The digesters were operated at both mesophilic and thermophilic temperatures, at 15-, 10-, and 5-day MCRTs. In addition, anaerobic food waste digestion was compared with anaerobic municipal wastewater solids digestion to demonstrate the benefits of food waste digestion at wastewater treatment plants.

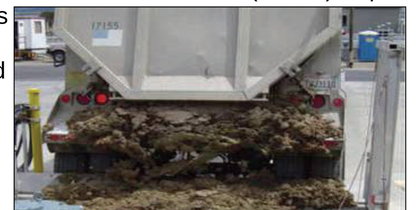

Figure 1. *Food waste delivery to the East Bay Municipal Utility District's wastewater treatment plant. The food waste is collected by a hauler and pre-processed by screening, grinding, and removing metal pieces. A typical delivery is approximately 20 tons total weight.*

Key digester design and operating criteria investigated included:
- Minimum MCRT.
- Volatile solids and chemical oxygen demand (COD) loading rates.
- Volatile solids destruction.
- Methane gas production rates.
- Process stability.
- Thermophilic and mesophilic operating temperatures.

Materials and Methods

Digesters
Two 30-L acrylic digesters were operated at either mesophilic or thermophilic temperatures, and at a 15- 10-, and 5- day MCRT during the study. There were a total of four feed cycles, and four sludge drawdown cycles occurring at six hour intervals throughout the day. The sludge drawdown cycle occurred before the feed cycle to prevent short-circuiting. The frequency and duration of the feed cycles were adjusted with a programmable two-channel timer. The drawdown cycles were adjusted similarly in order to meet the target MCRT. To maintain the temperatures in the mesophilic and thermophilic digesters at 35 ºC and 50 ºC, respectively, each digester was placed in a water bath with circulating immersion heaters (VWR International, Inc., 13271-010, West Chester, PA). Digesters and water bath temperatures were continuously monitored and logged using thermocouples and LabVIEW® Virtual Benchlogger™ software. The digesters were sealed to be gas tight with silicone sealant, and they were fed food waste pulp (produced from the EBMUD food waste process) semi-continuously at a set flow rate using a dual-head peristaltic pump and controller (Masterflex, Cole-Parmer, Chicago, IL). The contents of each digester was mixed continuously with an externally mounted variable-speed DC motor (Dayton Electrical Mfg. Co., 4Z128, Niles, IL) that turned a stainless steel shaft with two 4-inch diameter impellers. Biogas volumes produced by the digesters were measured using wet-tip gas meters (Wet Tip Gas Meter Co., Nashville, TN) with a digital totalizer that counts 1 unit per 100- mL of gas produced. To measure the digester sludge pH *in situ*, an 8-inch probe connected to an Orion 230A portable pH meter was inserted through a sampling port on the lid of the digesters.

Preparation of Feed
Five-gallon buckets of the final processed food waste slurry (called pulp) being fed to EBMUD's full-scale digesters were collected weekly and stored in a refrigerator (maintained at approximately 4 to 8 ºC) for feed to the bench-scale digesters. The food waste evaluated during this study is representative of food waste available from restaurants, grocery stores, and produce markets throughout California, and around the U.S. Food waste was collected from local restaurants, grocery stores, and other food handling facilities that source separate food waste, and then pre-processed by a local waste hauler.

The pre-processing included: screening to remove larger objects, a magnet to remove ferrous metals, and grinding to reduce particle size. After delivery of the pre-processed food waste by the hauler to EBMUD, the waste was slurried for pumping and underwent additional on-site processing to remove more contaminants.

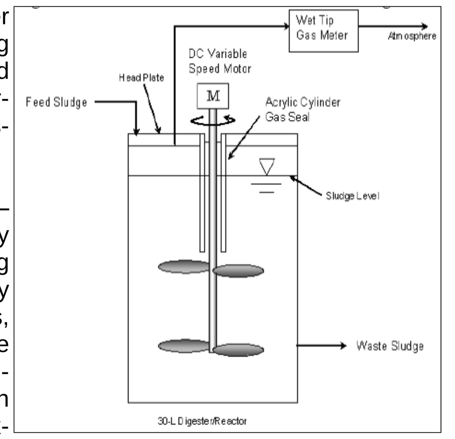

Figure 2. *Bench-scale Anaerobic Food Waste Digester Schematic*

The on-site processing (EBMUD food waste process—patent pending) included pumping the food waste slurry through a rock trap and grinder to remove any remaining large debris, and then passing the food waste slurry through a paddle finisher to remove grit and smaller debris, such as plastics, rubber bands, and chopsticks. The paddle finisher is composed of 2-4 paddles that rotate along the inside length of a cylindrical screen, with 0.040 or 0.065 inch openings; modifications to the size openings could be explored.
Soft biodegradeable materials are pushed and extruded through the screen. After passing through the screen this material is called "pulp" . The harder materials, which are not extrudable through the screen openings, is called "pomace." The pomace is transported by the paddles down the inside length of the screen and pushed out of the finisher. The pulp was pumped to EBMUD's anaerobic digesters and the pomace was trucked to a landfill, but might be recycled with a dry digester (producing more methane gas for electricity generation), gasification (producing a synthetic gas for electricity generation and less residual solids), or some other process.

The EBMUD process requires that all food waste materials be small enough so that the slurry can be pumped through the process, therefore, some form of material size reduction prior to the EBMUD process may be necessary. The process is shown schematically in Figure 2. The pulp produced during this study was sampled and fed to the bench-scale digesters (see Gray (Gabb), *et. al.*, 2008).

Sampling
During the effluent discharge cycle, the digester sludge was collected in sample containers for analysis. Gas samples were collected in glass syringes with a luer lock connection from the digester gas line to the wet-tip gas meter.

Laboratory Analysis
Feed and digester sludge samples were analyzed by the EBMUD Laboratory for total alkalinity (Standard Methods (SM), vol. 18, 2320B); total volatile acids (SM, vol. 18, 5560C); total ammonia (EPA 350.2/SM, vol. 20, 4500); total solids and volatile solids (SM, vol.18, 2540B, 2540 G/ EPA 160.3, 160.4); COD (SM, vol. 18, 5220D); fecal coliform (SM, vol. 18, 9221E); and gas composition (SM, vol. 18, 2720C). More specific information on the analytical methods can be found in the Quality Assurance Project Plan (QAPP).

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Results

Conclusions

The main conclusions from this study are as follows:
- The food waste evaluated during this study is representative of food waste available from restaurants, grocery stores, and produce markets throughout California, and around the U.S.
- Anaerobic digestion of food waste pulp from the EBMUD food waste process provides a higher normalized energy benefit, compared to municipal wastewater solids:
  - 730 to 1,300 kWh per dry ton of food waste applied.
  - 560 to 940 kWh per dry ton of municipal wastewater solids applied.
- Anaerobic digestion of food waste provides a higher normalized energy benefit at a 15-day MCRT than at a 10-day MCRT:
  - 90 to 320 kWh per wet ton of food waste at a 15-day MCRT, or the equivalent of satisfying the power demand of 800 to 1,400 homes per year at 100 tons of food waste per day.
  - 130 to 270 kWh per wet ton of food waste at a 10-day MCRT, or the equivalent of satisfying the power demand of 550 to 1,200 homes per year at100 tons of food waste per day.
- Food waste contains more biodegradable solids, with a higher VS/TS percentage (86% to 90%) than municipal wastewater solids (70% to 80%).
- Volatile solids destroyed (VSD) is higher for food waste when anaerobically digested (74 to 81%) than for municipal wastewater solids when anaerobically digested (57%), and much higher than the 38% VSD required by the EPA's 503 Regulations for land application.
- Since food waste is more readily biodegradable (i.e., with higher VS/TS and VSD) than municipal wastewater solids, a 10-day MCRT could be used rather than the minimum of 15-days for municipal wastewater solids anaerobic digestion. This means that food waste digestion also results in half the biosolids produced (residual solids) compared to anaerobically digesting municipal wastewater solids.
- Stable anaerobic digestion of food waste at both mesophilic and thermophilic temperatures provides more gas production (6 to 8.5 ft3 CH4/lb TS applied) than digestion of municipal wastewater solids (5 ft3 CH4/lb TS applied).
- Anaerobic digestion of food waste can occur at significantly higher VS loading (0.53 lb/ ft3-day) and COD loading (1.1 lb/ ft3-day) rates than typically seen for municipal wastewater solids (0.1 to 0.2 lb VS/ ft3-day and 0.06 to 0.3 lb COD/ ft3-day).
- Food waste digestion results in a nearly 3 times higher methane gas yield per digester volume at both 15-day (2,300 ft3 CH4/1000 ft3 digester volume) and10- day MCRT (2,600 ft3 CH4/1,000 ft3 digester volume) operation compared to that of municipal wastewater solids digestion (750 ft3 CH4/1,000 ft3 digester volume) at a 15-day MCRT.

Summary of Parameters Comparing Anaerobic Food Waste Digestion to Anaerobic Municipal Wastewater Solids Digestion

The results of this study demonstrate that anaerobic digestion of food waste can be achieved at a reduced MCRT (10 days), and at both mesophilic and thermophilic temperatures. Compared to municipal wastewater solids digestion, food waste digestion has many benefits. Food waste digestion is one alternative to composting since it can be done in a smaller foot print, and is a net energy producer rather than consumer. Table 1 summarizes the parameters comparing food waste digestion to municipal wastewater solids digestion.

Parameter	Units	Food Waste Digestion				Municipal Wastewater Solids Digestion
		15-day MCRT		10-day MCRT		15-day MCRT
		Meso	Thermo	Meso	Thermo	Meso(1)
VS (as percent of TS), Feed	%	86.3	87	89.9	90.6	77
VS Loading, Feed	lb/ft^3-day	0.28	0.29	0.53	0.54	0.2(2)
COD Loading, Feed	lb/ft^3-day	0.55	0.57	1.09	1.11	0.06-0.3(3)
VSD	%	73.8	80.8	76.4	82.4	38-57%(4)
Methane (CH_4) Content	%	64	67	59	60	63
Methane Production Rate, Avg (Range)	ft^3/lb TS applied	13,300 (9,800–17,000)(5)		9,500 (6,600–14,400)(5)		10,000 (7,500–12,600)
	ft^3 per day/ 1,000 ft^3 digester volume	2,300 (1,100–3,200)		2,600 (1,800–3,800)		750 (550–930)
Residuals (Mass of Biosolids Produced) as a Percent of Feed Applied	%	36	30	31	26	56-70

Notes:
1. Based on data from previous EBMUD bench-scale pilot study. Digesters were fed thickened waste activated sludge and screened primary sludge.
2. Maximum recommended loading rate, WEF MOP 8.
3. Maximum recommended loading rate, M&E, 4th Edition.
4. EPA 503 Regulations minimum is 38%. Typical average is 57% from EBMUD bench-scale pilot study.
5. Data combined for mesophilic and thermophilic digesters

Table 1. *Summary of Parameters Comparing Anaerobic Food Waste Digestion to Anaerobic Municipal Wastewater Solids Digestion.*

Digester Gas Production and Composition

Gas Production
Organic carbon (as represented by chemical or biochemical oxygen demand) is removed in anaerobic digesters through its conversion into methane and carbon dioxide gas by methanogenic bacteria. Gas production is an indicator of how well the anaerobic digestion process is performing. Gas production is influenced by the characteristics of the waste stream applied to the digester, digester temperature, and organic loading rate to the digester. For example, fats and greases have a higher gas production rate per unit mass destroyed than proteins or carbohydrates. Gas production will also be influenced by how readily wastes are biodegraded.

15-day MCRT
The thermophilic digester showed a steady increase in gas production prior to the switch to 10-day MCRT operation. Fluctuation in gas production was observed in both digesters. During stable operational periods, the gas production averaged 4.8 L/ hr (standard deviation 1.6 L/hr) for the thermophilic digester, and 4 L/hr (standard deviation 0.7 L/hr) for the mesophilic digester.

Compared to the average gas production of 1.3 L/hr at a 15-day MCRT from a previous EBMUD digestion pilot study feeding municipal wastewater solids, **food waste provides over a 3 fold increase in gas production**. Based on the data in this study, gas production appears to increase when anaerobic digesters are operated at thermophilic rather than mesophilic temperatures, which may be attributed to the higher growth rate of the methanogens at higher temperatures.

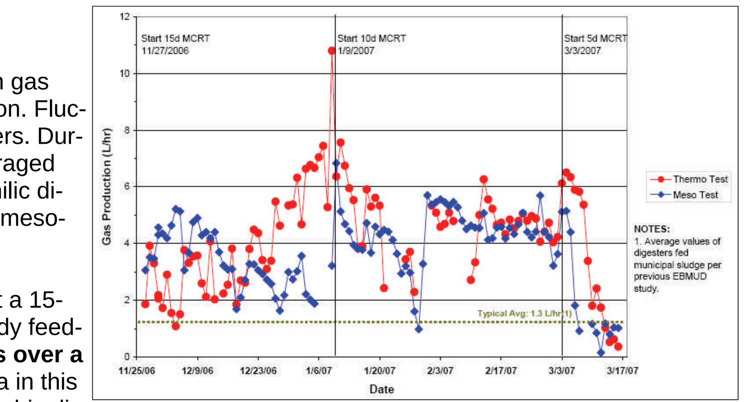

Figure 4. *Anaerobic Food Waste Digester Gas Production*

10-day MCRT
During stable operational periods, the gas production averaged 5.4 L/ hr (standard deviation 1.5 L/hr) for the thermophilic digester and 4.5 L/hr (standard deviation 0.8 L/hr) for the mesophilic digester. Average gas production increased during the 10-day MCRT operational period, compared to the 15-day MCRT period, resulting from an increase in organic loading to the digesters.

Target MCRT, days	Mesophilic Digester Methane (CH_4), %		Thermophilic Digester Methane (CH_4), %	
	AVG	SD	AVG	SD
15	64	0.6	67	6.1
10	59	3.5	60	4.4
5	NA	NA	NA	NA

Notes:
1. AVG=average value.
2. SD= standard deviation.
3. NA=Not Applicable because only one data point was observed during stable period.

Table 3 . *Bench-scale Anaerobic Food Waste Digester Methane Gas Composition*

5-day MCRT
Gas production first increased sharply and then dropped off sharply when both thermophilic and mesophilic digesters were operated at a 5-day MCRT; although gas production was typically higher in the thermophilic digester compared to the mesophilic digester. The lower gas production was likely due to the methanogens growth rate being too slow for the 5-day MCRT, resulting in a washout of methanogens.

Digester Gas Composition
During methanogenesis, methane (CH_4) and carbon dioxide (CO_2) make up almost all of the digester gas produced. Combining methane and carbon dioxide usually accounts for nearly 99% or more of the digester gas content, with methane at about 60-65% and carbon dioxide at about 35-40%. The methane and carbon dioxide concentrations can be used as an indicator of digester process stability. During the 15-day MCRT operational period, both mesophilic and thermophilic digesters produced gas with a higher methane content than during the shorter MCRT periods, which suggests that a longer MCRT allows larger methanogen populations to optimize methane production.

Volatile Solids Destruction

Volatile Solids Destruction (VSD) is used to monitor digester stability. VSD is a function of digester feed, temperature, and MCRT. Municipal wastewater solids are typically composed of primary sludge and thickened waste activated sludge. Primary sludge degrades more readily than waste activated sludge. By increasing VSD, less residuals are produced, which decreases hauling costs, and more methane is usually formed.

Throughout the study at 15-, 10-, and 5-day MCRTs, VSD in the digesters appeared to stabilize at approximately 80%, with some peaks near 90%, but both the thermophilic and mesophilic digesters were consistently above the average range of 50% to 60% VSD for municipal wastewater solids digestion. Also, the VSD is well above the minimum of 38% required by the EPA 503 regulations for biosolids land application. **This indicates that food waste is significantly more biodegradable than municipal wastewater solids.**

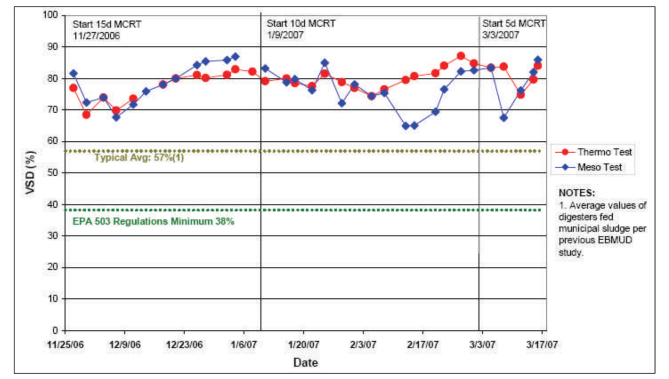

Figure 6. *Anaerobic Food Waste Digester Volatile Solids Destruction*

Total Solids and Volatile Solids
Total solids (TS) and volatile solids (VS) are both used to monitor the solids content (as a mass percent) of the digester feed, and the digester contents. Percent VS represents the organic, or biodegradable fraction of the feed. VS, combined with the MCRT and digester volume, can be used to determine the digester VS loading rate. The difference between TS and VS is referred to as inert solids that pass through the digestion process.

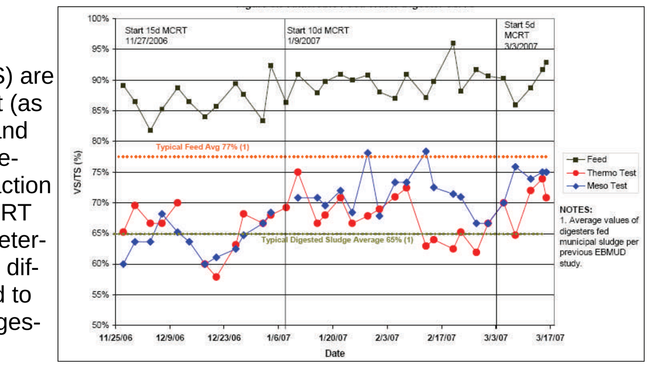

Figure 7. *Anaerobic Food Waste Digester VS/TS*

The VS in the digester effluent is used to calculate the VS removed or destroyed. TS and VS, along with MCRT and digester volume, can also be used to determine the residual biomass remaining after digestion.

Mean Cell Residence Time

The mean cell residence time (MCRT) is the theoretical average time a bacterial cell remains in a digester. The MCRT is a key parameter that is used to control process stability and determine the required digester volume. Longer MCRTs generally result in a more stable process and a higher degree of solids stabilization; however, this requires larger digesters and greater capital funding. Therefore, a tradeoff exists between process stability and capital costs. In the municipal wastewater treatment industry, the minimum MCRT for an anaerobic digester is 15 days to meet the Class B requirements of the 503 regulations.

Food waste is composed of organic material that are readily biodegradable. Municipal wastewater solids contain human waste that has already decomposed to a certain degree and is more resistant to further degradation. Because food waste is more biodegradable than municipal wastewater solids, operating digesters fed only food waste at shorter MCRTs should be feasible. The benchmark 15-day MCRT was included in this study as a reference for comparison to the digestion of municipal wastewater solids, but 10- and 5-day MCRTs were also investigated to determine the minimum MCRT required for food waste.

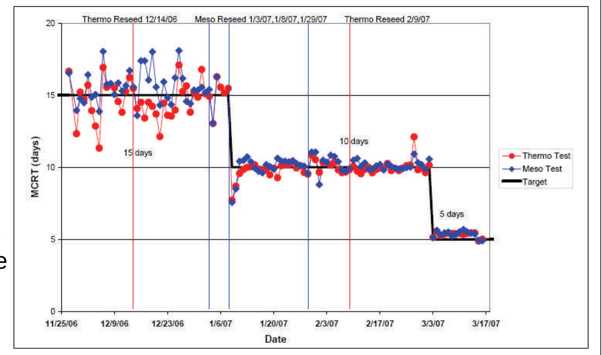

Figure 3. *Anaerobic Food Waste Digester Mean Cell Residence Time*

The equation used to calculate MCRT is as follows:

$$\textit{MCRT, days} = \frac{\textit{Active digester volume , L}}{\textit{Daily digester sludge volume wasted, L/day}}$$

Target MCRT, days	Mesophilic Digester MCRT, days		Thermophilic Digester MCRT, days	
	AVG	SD	AVG	SD
15	15.6	1.2	14.7	1.2
10	10.1	0.6	9.9	0.7
5	5.3	0.2	5.3	0.3

Notes:
1. AVG=average value.
2. SD= standard deviation.

Table 2. *Bench-scale Anaerobic Food Waste Digester MCRT Summary.*

Figure 5. *Food waste being unloaded at the EBMUD Treatment Plant*

Chemical Oxygen Demand (COD) Loading Rate

The COD loading rate was monitored to determine the organic strength of food waste, and then was compared to the organic strength of municipal wastewater solids. The COD loading rate is comparable to VS loading rate. For municipal wastewater solids digestion, COD loading rates can be used to monitor and prevent digester upset, possibly resulting from ammonia and/or other compounds found in wastewater solids reaching toxic levels due to higher feed rates.

COD loading rate was calculated using the following equation:

$$\textit{CODload (lb/ ft3-day)} = \frac{\textit{CODfeed (mg/L) X Feed Rate (L/day)} \times \textit{0.000062 (Conversion Factor)}}{\textit{igester Volume (L)}}$$

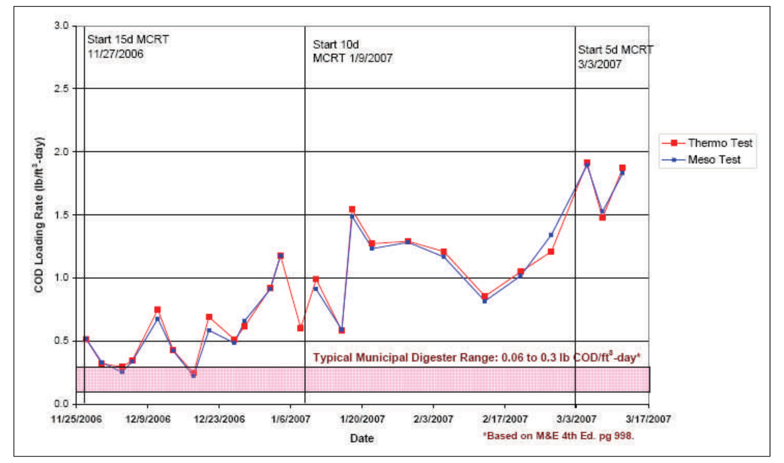

Figure 8. *Anaerobic Food Waste Digester COD Loading Rate*

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To maintain a healthy population of methanogens, the pH in an anaerobic digester is typically maintained between 7 and 7.5. The pH is maintained by a balance between the acetogens and methanogens. Acetogens produce acid, and methanogens consume acid (increasing alkalinity) to produce methane gas. Therefore, if the acetogens outpace the methanogens, the pH will drop, which can inhibit methanogens, and ultimately lead to an upset, or 'sour' digester.

The means to anticipate a significant pH drop is to monitor digester sludge volatile acids, alkalinity, and gas quality and production, which is discussed in subsequent sections. pH is not a sensitive monitoring process parameter, as a significant change may indicate it is too late to makeadjustments to stabilize digester operation, and will most likely require a long period of time to recover.

For most of the study, the pH remained in a stable operating range between 7 and 8, which was consistent with the average pH of 7.44 during previous EBMUD bench-scale anaerobic digestion studies. There were a few occurrences when the digester pH dropped significantly, which indicated unstable operation and required restarting the digesters with new seed sludge from EBMUD's full-scale digesters.

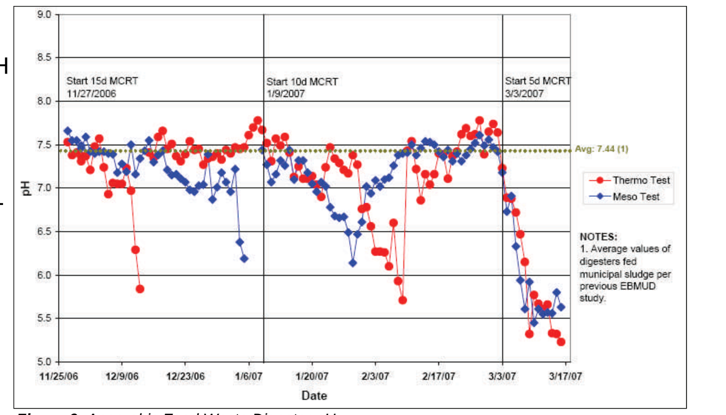

Figure 9. *Anaerobic Food Waste Digester pH*